Astronomical and Astrophysical Transactions (*AApTr*), 2010/2011, Vol. 27, Issue 1, pp. 73–81,
ISSN 1055-6796, Photocopying permitted by license only, ©Cambridge Scientific Publishers

The new era of variable-star catalogues

N.N. SAMUS[1,2,3*] AND E.V. KAZAROVETS[1†]

[1]*Institute of Astronomy, Russian Academy of Sciences, 48, Pyatnitskaya Str., Moscow 119017, Russia;*
[2]*Sternberg Astronomical Institute, Moscow University, 13, University Ave., Moscow 119992, Russia;*
[3]*Euro-Asian Astronomical Society, 13, University Ave., Moscow 119992, Russia*

Received 31 October, 2008

We present a brief review of the history of catalogues of variable stars, discuss current problems of variable-star catalogues (completeness, positional accuracy, classification system, etc.) and their future.

Keywords: Variable stars; Star catalogues

1 Introduction

This paper, based on the invited talk presented during the conference "Astronomy and Astrophysics of the Beginning of the 21st century" (July 2008), is a result of our team work on the General Catalogue of Variable Stars (GCVS), performed on behalf of the IAU Division V (Commissions 27 and 42). Understanding the past of variable-star catalogues and the current state of work is important from the point of view of the GCVS future considered by the Division V during the Rio-de-Janeiro General Assembly of the IAU in 2009.

2 A brief history of variable-star catalogues

The first variable-star catalogue we know of was compiled by Edward Pigott in 1786. It contains 4 Mira variables, 2 Cepheids, 2 eclipsing stars, 2 stars now called Supernovae, 1 Nova and the unique variable P Cygni. Before the era of astronomical photography, the number of known variable stars increased very slowly, and the catalogue published more than half a century later (in 1844) by Argelander [1] contained only 18 stars, one of them (α Cas) is still considered an unconfirmed variable star even now.

*Email: samus@sai.msu.ru
†Email: helene@inasan.ru

After World War I, the catalogues of variable stars were compiled and published under the auspices of the "Astronomische Gesellschaft" (AG), formerly a world-wide astronomical society whose role as the organizer of world astronomy was transferred to the IAU founded in 1919. The AG then chose several projects of international importance that it could coordinate, keeping the Society's international significance. Catalogues of variable stars were one of these projects.

Between 1926 and 1942, a catalogue, with ephemerides for the next year, was yearly published by the Berlin–Babelsberg Observatory. Each catalogue was designed to completely replace the previous one. For several years, the catalogues were compiled by Richard Prager (1883–1945), an outstanding variable-star expert. He suffered persecution during the Nazi regime and had to emigrate, and his work was continued by another German astronomer, Heribert Schneller. After 1942, it became completely impossible to continue the catalogue work in Germany. The first AG catalogue [2] contained 2906 stars; the number of stars in the last AG catalogue [3] was 9476.

The AG catalogues (and the GCVS now) include only *named* variable stars, i.e. those designated in the system standard for variable stars. To be named, the star should be a confirmed, sufficiently well-studied variable. Other variable stars are called suspected variables and listed in special catalogues. The history of these catalogues also dates back to the 19th century. The system of the AG catalogues contains three catalogues of suspected variable stars supplementing each other, with a total of 8020 stars [4–6].

An interesting addition to the AG catalogues is the many-volume publication "Geschichte und Literatur..." ("History and Literature..."). It contains a rather complete bibliography of each named variable star and a text description of the history of its discovery and studies. The first edition [7] actually appeared before the first AG catalogue. The second edition, initiated in 1930s [8], was finished only some 30 years later [9]. This project was continued for some time in the Sonneberg Observatory as an electronic catalogue.

After World War II, the IAU decided to transfer several German projects to other countries. Two of them were made the responsibility of astronomers of the Soviet Union. Ephemerides of minor planets became the project of the Institute of Theoretical Astronomy in Leningrad (St. Petersburg). A Moscow team in the Academy of Sciences and Moscow University was made responsible for catalogues of variable stars in 1946. The decision of the IAU Executive Committee was taken after a sufficiently thorough analysis of possibilities, including visits of IAU officers to suggested institutions. In the case of variable-star catalogues, the choice of Moscow was based on the existence of an experienced team of researchers, with a detailed card catalogue of variable stars kept since 1930s on the initiative of Prof. Pavel Parenago (1906–1960), who, together with Prof. Boris Kukarkin (1909–1977), became leaders of the project. Since then, the catalogue work is being continued in the Academy (currently at the department of non-stable stars and stellar spectroscopy of the Institute of Astronomy) and the University (currently at the Department of Galactic Studies and Variable Stars of the Sternberg Institute).

The Moscow catalogues of variable stars never attempted yearly publication. Instead, it was decided to publish Supplements between major editions, each Supplement containing only newly named variables and stars with significantly altered catalogue data. The first Soviet catalogue, called the "General Catalogue of Variable

Stars" (GCVS), was published soon after the IAU decision [10]. The number of stars in this catalogue (10930) is not much larger than in the last Schneller's catalogue, most probably reflecting an actual slow-down of variable-star discoveries during the war time.

The first Soviet catalogue of suspected variable stars (CVS), contained 5835 variables insufficiently studied for being named, plus 2299 stars considered by the catalogue authors as suspected without convincing grounds, appeared three years later [11]. In its author team, we see the name of Prof. Pavel Kholopov (1922–1988), one of the leaders of the GCVS project from the very beginning and the formal head of the project after Kukarkin's death in 1977.

Later, the second (two-volume) GCVS edition [12], which replaced the first one, and the second CSV [13], supplementing the first one (about 4000 suspected variables) were published. The third (three-volume) GCVS edition [14] contained, for the first time, the tables of optically variable quasars and galactic nuclei. These extragalactic parts of the 3rd GCVS edition were mainly contributed by Prof. Yuri Pskovski (1926–2004).

Now we come to the 4th edition of the GCVS, probably the last one to be ever published in paper form. It was started with the New Catalogue of Suspected Variable Stars [15]. The catalogue (14811 stars) replaced the two suspected-variable catalogues of 1951 and 1965. Later on, a supplement was added containing 11206 stars [16].

In 1985–1987, the GCVS team published three main volumes of the 4th edition [17] containing information on 28435 variable stars. After P.N. Kholopov's death in 1988, Nikolay Samus was appointed the head of the project. The fourth GCVS volume [18] contains various reference tables. Cross-identification tables permit us to find the GCVS name for a star with known name in one of the major astronomical catalogues, like the Henry Draper Catalogue, Durchmusterungen (BD, CoD, CPD), and many other sources.

The edition was finished only 10 years after the appearance of its first volume, with the fifth volume dealing with extragalactic variable stars [19]. It presents data on about 11000 variable stars in external galaxies (without Supernovae) and almost 1000 extragalactic Supernovae. The publication of the extragalactic volume was delayed because it had been decided to improve the accuracy of coordinates. At that time, the standard precision of coordinates in the main GCVS volumes was to 1^s in right ascension and to $0'.1$ in declination, not good enough even for galactic variables and quite insufficient for extragalactic stars. Measuring coordinates with ten times better precision took much time. P.N. Kholopov's idea to expand the GCVS to variable stars outside our Galaxy gave an interesting result, but the very strong flow of new information made the GCVS Volume V obsolete very quickly, and so far we are not planning to continue activity in the field of extragalactic variable stars.

For reasons of tradition not easy to explain, variable stars in globular clusters (in variance to open-cluster variables) are, as a rule, not included in the GCVS. Their catalogues are published separately. The third catalogue of variable stars in globular clusters [20] contains 2119 stars. A specific feature of this catalogue is that it does not present equatorial coordinates for most stars but formally accurate (actually heterogeneous) rectangular coordinates with reference to roughly specified cluster centers.

3 Variable-star catalogues: Current state and future Prospects

Current versions of the GCVS and of suspected-variable catalogues can be found at the site of the GCVS team (http://www.sai.msu.su/gcvs/gcvs/).

Stars are added to the GCVS via Name-Lists. In the recent decades, all the Name-Lists were published in the IAU Commissions 27 and 42 Information Bulletin on Variable Stars. With the most recently published Name-List (No. 78, [21]), the number of stars already named in the GCVS system exceeds 46200.

Since the completion of the 4th edition of the GCVS, our team introduced a new accuracy standard of catalogued coordinates (to $0^s.01$ in right ascension and $0''.1$ in declination) and completely revised coordinates of all GCVS stars, widely using published and unpublished finding charts for identifications with modern catalogues of stellar positions ([22] and references therein). We were able to identify, quite reliably or with some level of uncertainty, virtually all GCVS stars; only some 200 stars could not be found. A similar work is under way for stars of the NSV catalogue.

After the death of Helen Sawyer Hogg (1905–1993), her team, headed by Christine Coutts Clement, continues its work on the catalogue of variable stars in globular clusters (CVSGC; cf. [23]). The current electronic version (about 3000 stars) can be found at the catalogue's web site (http://www.astro.utoronto.ca/ ∼cclement/read.html). The GCVS team highly appreciates the work of the Canadian team, considering specialized variable-star catalogues always useful, but finds it logical to add those variables in globular clusters that meet our naming rules (reliable, sufficiently studied variables) to the GCVS. To do it, it is necessary to find equatorial coordinates for all globular-cluster variable stars because only a small fraction of stars already have equatorial coordinates in the CVSGC. This preliminary work is almost completed [24]. It revealed quite a number of mistakes in the CVSGC, many of them copied from original publications. Among 2100 stars of the CVSGC analyzed by August, 2008, we found 199 stars already in the GCVS or the NSV catalogue, with only 9 of these names mentioned in the CVSGC.

The advent of large-scale automatic sky surveys opens new possibilities for variable-star studies but simultaneously creates new challenges for variable-star catalogue compilers. Among several recent sky surveys, the ongoing ASAS-3 survey (The All-Sky Automatic Survey, [25]) is best-suited for our purposes. It provides access to V-band CCD observations (from year 2000 till now) for millions of stars in the magnitude range between 8.5 and 15. The survey, limited to the southern sky (from the southern pole to the declination $+28°$), resulted in its own catalogue of variable stars (about 50000, some 30000 of them believed to be new).

A northern analog of the ASAS-3 is the NSVS (The Northern Sky Variability Survey, [26]), a part of the ROTSE-I survey devoted to microlensing effects. It covers the sky from the northern pole to the declination $-38°$ in the south. Again, it provides access to CCD observations of millions of stars. However, the time coverage of the publicly available data is limited to less than a year in 1999–2000, and the photometric system is not standard, as in the V-band ASAS-3 survey, but red instrumental. The authors of the survey have not finished the analysis of their data from the point of view of variability discoveries but already have announced several thousands of new variable stars.

Quite a number of other surveys exist (OGLE, MACHO, MISAO, etc.), some of

them with much larger telescopes than in the case of ASAS-3 or NSVS, others modest, but the above two surveys are the most important ones for our catalogue work. They have completely changed the situation with comparatively bright variable stars. If a 13^m star was considered not bright when photographic plates had been principal light detectors and thus could attract no attention for decades, currently it is rather easy to check its photometric behavior in the recent years and to correct/append the catalogue information. It is possible to find many "suspected" variable stars, study them, and transfer them to the GCVS from the NSV catalogue. One of the first results of such an approach is the 79th Name-List of Variable Stars [27], with more than 1200 NSV stars named in the GCVS system.

The availability of observations for virtually any star bright enough for automatic surveys has created a new kind of astronomical research, the so-called "data mining". Amateurs as well as professional astronomers are now able to discover and study genuine variable stars without the need to acquire their own observations, just using publicly available data. Unfortunately, some scientific journals started the policy of not accepting announcements of variable-star discoveries based solely on data mining. In our opinion, any discovery of a variable star should be published, and we keep our English-language electronic journal "Peremennye Zvezdy" (Variable Stars) open to such announcements (see http://www.astronet.ru/db/varstars/msg/1209090). This electronic journal continues the well-known Russian journal founded by B.V. Kukarkin in 1928 (volumes 1–24 of the main journal and 1–4 of the supplement were published in the paper form, and further volumes are in electronic form only).

One of the most difficult problems currently facing the GCVS team is what to do with thousands of new variable stars announced as a result of the major automatic surveys. The best solution would be to quickly incorporate them in the GCVS. However, this cannot be immediately done for several reasons. The first of them is low accuracy of coordinates in most of the automatic surveys. With a characteristic scale of $15''$ per pixel in the surveys like ASAS-3 or NSVS, it is not an uncommon thing to find a "variable star" in several seconds from its true position, shifted towards a neighbor of comparable magnitude. To check which of the two stars varies would require special observations, and to use the existing coordinates in the catalogue would mean a deterioration in the currently good positional accuracy of the GCVS (see above).

The second problem is related to automatic methods of finding periods and classifying variable stars applied in the automatic surveys. For example, the ASAS-3 variable star catalogue effectively uses only 12 types of variable stars, and the type with the largest number of objects is called "Miscellaneous" – i.e. not belonging to other 11 types. Admittedly, the current GCVS classification system contains too many types for easy understanding, and we are planning to simplify it. However, it would be against the interests of the GCVS users to "simplify" it to the level of impossibility of an informed judgment on the expected character of variations for a catalogued star. Also, we often find unreliable periods, poorly determined times of brightness maxima or minima in the catalogues provided in the surveys. For example, the star ASAS 004506-1854.2 is called a Cepheid in the ASAS-3 catalogue. With the catalogued period of 106 days, it becomes the longest-period Cepheid of our Galaxy, a potentially important fact not noticed by the compilers of the ASAS-3 catalogue. However, Khruslov [28] carefully reduced the ASAS-3 and NSVS data to demonstrate

that, beyond doubt, this star was an RR Lyrae variable with a period close to half a day (a well-known possibility of aliases of periods close to one day or half a day that make stars resemble long-period variables).

The policy we follow with respect of the discoveries from the automatic surveys is the following. We consider the catalogues like that suggested by ASAS-3 more or less self-sufficient for now. Stars from them will be named in the GCVS system if they appear in scientific literature as objects of new detailed studies or as a result of our own investigations, including checks for NSV stars. Note that variable stars from our catalogues as well as those from most surveys can be found in the variable star index provided by the AASVO, a very important compilative source of information on variable stars (http://www.aavso.org/vsx/).

We also actively use observations from automatic surveys to improve astrophysical information in the GCVS. Our first release of the GCVS version revised using ASAS-3 data and data from new publications [29] contained data for more than 1300 variable stars in three southern constellations. The GCVS web site (http://www.sai.msu.su/gcvs/gcvs/), where the newest GCVS versions can be found, currently provides revised data for three more constellations taking into account ASAS-3 as well as NSVS data.

4 Digitizing plate collections

Stacks of astronomical photographs are still an important source of information complementing modern photoelectric and CCD observations. This information was only partially used during the century of the photographic era in astronomy, and its complete incorporation in astronomical research depends on its future availability in the digital form.

Some observatories possess especially rich plate collections. The Harvard plate stacks (USA) store over 500000 plates; some 300000 plates are kept in the plate archive of the Sonneberg Observatory (Germany). Since the 1990s, many observatories started attempts to digitize their plate collections. The digitization project of the Harvard Observatory [30] is apparently the only one so far that uses specialized high-productivity scanners designed and produced for the project. According to the Sonneberg Observatory web site (http://www.stw.tu-ilmenau.de/observatory/observatory_2.html), more than 200000 plates were digitized as of October, 2008 with commercially available scanners of a somewhat insufficient linear resolution.

So far, most observatories are still working on their digitization projects. To our knowledge, only the Maria Mitchell Observatory (USA) has finished digitizing its collection of direct sky photographs, which, however, is small (about 8000 plates; cf. http://www.aas.org/~pboyce/mma/plates.htm).

Regular photographic observations of the sky for variable-star studies were started in Moscow in 1895. Since then, several different telescopes were used to take direct sky plates for astrometry and for astrophysics. The Moscow plate archive now contains more than 60000 direct photographs and objective-prism plates taken in Moscow, at other sites in Russia, and at the Sternberg Institute's laboratory in Crimea, Ukraine.

The most important part of the Moscow plate collection are direct sky photographs acquired in 1948–1996 with a 40-cm astrograph. This instrument was ordered for Sonneberg Observatory and first installed there in 1938. 1658 plates from this telescope,

taken in 1938–1945, are kept in Sonneberg. In 1945, the telescope was taken to the Soviet Union as a part of the World War II reparations. It was initially installed in Simeiz (Crimea), then brought to Kuchino near Moscow, and in 1958 became the first instrument of the Crimean Laboratory of the Sternberg Institute in Nauchny, Crimea. The total number of plates taken with the 40-cm astrograph after 1948 is about 22500.

A characteristic feature of the comparatively small Moscow plate collection is its very good average quality of well-kept plates and the large number of plates in some fields of interest for variable-star research.

The work on digitizing the plate stacks in Moscow [31] began in 2004, after the purchase of two Creo EverSmart Supreme II scanners. The plates are scanned with a resolution of 2540 dpi (1.2 arcseconds per pixel in the case of the 40-cm astrograph). By October 2008, about 1000 plates were scanned completely and some 1000 plates, partially, for different experiments.

We have begun applying algorithms of semi-automatic search for variable stars to scans of the Moscow collection plates. In 2008, we studied scans of 254 plates of the field centered at the star 66 Oph, taken in 1976–1995. In the northern half of the field ($10^\circ \times 5^\circ$), earlier repeatedly studied for variable stars by different authors, we discovered and studied [32] 274 new variables among stars in the $13\overset{\mathrm{m}}{.}5$–$16\overset{\mathrm{m}}{.}5$ B range. The list of our new variables contains 2 probable Population II Cepheids; 81 eclipsing variables; 5 high-amplitude δ Scuti stars (HADSs); 82 RR Lyraes; 62 red irregular variables and 41 red semiregular stars; 1 slow irregular variable not red in color. These variables are ready to be included into the GCVS.

5 Conclusions

Catalogues of variable stars are currently experiencing an interesting and complicated period. The very strong flow of new information, discoveries of thousands of new variable stars make it impossible to use traditional, manual, star-to-star techniques of catalogue compilation. On the other hand, unthoughtful application of automatic methods can introduce an unacceptable number of errors and make the catalogues less useful for the astronomical community.

The IAU Commissions 27 and 42 created a working group to consider problems of variable-star catalogues at the current stage and are going to discuss the future of the catalogues at the Rio-de-Janeiro IAU General Assembly. Relevant material can be found at our site (http://www.sai.msu.su/gcvs/future/future.html). We appeal to astronomers of the world to communicate their suggestions to us.

Acknowledgements

Thanks are due to our colleagues who have been engaged in the time- and effort-consuming work on variable-star catalogues for decades, often with no time left for their personal scientific interests. Our work is supported, in part, by the Russian Foundation for Basic Research (grant No. 08-02-00375), the Program "Origin and

Evolution of Stars and Galaxies" of the Presidium of Russian Academy of Science, and the Program of Support for Leading Scientific Schools of Russia (grant No. NSh 433.2008.2).

References

[1] Argelander, F., 1844, in: *Jahrbuch für 1844*, herausgegeben von H.C. Schumacher, Stuttgart und Tübingen: Cotta, S. 122
[2] Prager, R., 1926, *Kl. Veröff. Universitätssternw. Berlin–Babelsberg*, Nr. 1
[3] Schneller, H., 1942, *Kl. Veröff. Universitätssternw. Berlin–Babelsberg*, Nr. 26
[4] Zinner, E., 1929, *Ergänz. Astron. Nachr.*, 8, Nr. 1
[5] Prager, R., 1934a, *Ergänz. Astron. Nachr.*, 9, Nr. 3
[6] Prager, R., 1937, *Ergänz. Astron. Nachr.*, 10, Nr. 1
[7] Müller, G., Hartwig, E., 1918–1922, *Geschichte und Literatur des Lichtwechsels der bis Ende 1915 als sicher veränderlich anerkannten Sterne*, Bände 1–3, Leipzig
[8] Prager, R., 1934b, *Geschichte und Literatur des Lichtwechsels der Veränderlichen Sterne*, 2. Ausgabe, Bd. I, Berlin: F. Dümmler
[9] Schneller, H., 1963, *Geschichte und Literatur des Lichtwechsels der Veränderlichen Sterne*, Bd. V, H. 3
[10] Kukarkin, B.V., Parenago, P.P., 1948, *The General Catalogue of Variable Stars*, Moscow and Leningrad: Publishing House of the USSR Academy of Sciences
[11] Kukarkin, B.V., Parenago, P.P., Efremov, Yu.I., Kholopov, P.N., 1951, *A Catalogue of Suspected Variable Stars*, Moscow: Publishing House of the USSR Academy of Sciences
[12] Kukarkin, B.V., Parenago, P.P., Efremov, Yu.I., Kholopov, P.N., 1958, *The General Catalogue of Variable Stars*, 2nd Edition, Vols. I and II, Moscow: Publishing House of the USSR Academy of Sciences
[13] Kukarkin, B.V., Kholopov, P.N., Efremov, Yu.N., Kurochkin, N.E., 1965, *The Second Catalogue of Suspected Variable Stars*, Moscow: Astrosoviet and Sternberg Institute
[14] Kukarkin, B.V., Kholopov, P.N., Efremov, Yu.N., et al., 1969–1971, *The General Catalogue of Variable Stars*, 3rd Edition, Vol. I, II, and III, Moscow: Astrosoviet
[15] Kukarkin, B.V., Kholopov, P.N., Artyukhina, N.M., et al., 1982, *The New Catalogue of Suspected Variable Stars*, Moscow: Nauka
[16] Kazarovets, E.V., Samus, N.N., Durlevich, O.V., 1998, *Information Bulletin on Var. Stars*, No. 4655
[17] Kholopov, P.N., Samus, N.N., Frolov, M.S., et al., 1985–1987, *The General Catalogue of Variable Stars*, 4rd Edition, Vol. I, II, and III, Moscow: Nauka
[18] Kholopov, P.N., Samus, N.N., Durlevich, O.V., et al., 1989, *The General Catalogue of Variable Stars*, 4rd Edition, Vol. IV, Moscow: Nauka
[19] Artyukhina, N.M., Durlevich, O.V., Frolov, M.S., et al., 1995, *The General Catalogue of Variable Stars*, 4rd Edition, Vol. V, Moscow: Kosmosinform
[20] Sawyer Hogg, H., 1973, *Publ. David Dunlap Observatory*, **3**, No. 6
[21] Kazarovets, E.V., Samus, N.N., Durlevich, O.V., et al., 2006, *Information Bulletin on Var. Stars*, No. 5721
[22] Samus, N.N., Durlevich, O.V., Zharova, A.V., et al., 2006a, *Astronomy Letters*, **32**, 263

[23] Clement, C.M., Muzzin, A., Dufton, Q., et al., 2001, *Astron. J.*, 122, 2587
[24] Samus, N.N., Kazarovets, E.V., Pastukhova, E.N., Tsvetkova, T.M., 2008, Poster presented at Symposium 5 "Star Clusters – Witnesses of Cosmic History" of the Joint European and National Astronomy Meeting, Vienna
[25] Pojmanski, G., 2002, *Acta Astronomica*, 52, 397
[26] Woźniak, P.R., Vestrand, W.T., Akerlof, C.W., et al., 2004, *Astron. J.*, 127, 2436
[27] Kazarovets, E.V., Samus, N.N., Durlevich, O.V., et al., 2008, *Information Bulletin on Var. Stars*, No. 5863
[28] Khruslov, A., 2005, *Peremennye Zvezdy (Supplement)*, **5**, No. 8
[29] Samus, N.N., Pastukhova, E.N., Durlevich, O.V., 2007, *Peremennye Zvezdy*, **27**, No. 6
[30] Mink, D., Doane, A., Simcoe, R., et al., 2006, in: *Virtual Observatory: Plate Content Digitization, Archive Mining and Image Sequence Processing*, M. Tsvetkov et al. (eds.), Sofia: Heron Press, p. 54
[31] Samus, N.N., Sat, L.A., Vereshchagin, S.V., Zharova, A.V., 2006b, in: *Virtual Observatory: Plate Content Digitization, Archive Mining and Image Sequence Processing*, M. Tsvetkov et al. (eds.), Sofia: Heron Press, p. 103
[32] Kolesnikova, D.M., Sat, L.A., Sokolovsky, K.V., et al., 2008, *Acta Astronomica*, **58**, 279